COMPACT LPF DESIGN WITH LOW CUTOFF FREQUENCY USING V-SHAPED DGS STRUCTURE

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ABSTRACT

A class of compact microstrip Low Pass Filter (LPF) with low 3dB cutoff frequency, ultrabroad stopband, and high stopband attenuation characteristics is introduced. It employs both shaped transmission line and Defected Ground Structure (DGS) techniques to achieve the aforementioned characteristics. In this paper, a new V-shaped DGS structure is introduced. The dimensions of the V-shaped DGS control the 3dB cutoff frequency of the filter. On the basis of this study, different low pass filters having 3dB cutoff frequencies ranging from 1.2GHz to 1.688GHz are designed. A comparison with the low pass filter implemented using double U-shaped DGS structure having same substrate area is carried out. The simulations results indicate that the proposed filter exhibits much lower cutoff frequency than the double U-shaped filter while maintain the same compact size. At 1.688 GHz 3dB cutoff frequency, a wide stopband bandwidth with attenuation level more than 20dB from 2.22 GHz to 7.12 GHz is obtained. Moreover, the occupied area is only (20×19) mm² as the same area of the original U-shaped filter. Good agreement between the measurements and simulation results is observed.

Index Terms: Defected Ground Structure (DGS), Microstrip Low Pass Filter (LPF), Ultrabroad Stopband.
I. INTRODUCTION

Microwave low pass filters are essential devices in RF wireless communication systems to remove noise, harmonics and other spurious signals. For these circuits, size compactness and high power attenuation levels throughout a broad stopband spectral range are desired properties to efficiently accomplish this task. Different techniques have been investigated i.e. using resonators, shaped transmission lines, and defected ground structures to achieve miniaturization of microwave filters. More recent approaches to develop quasi-elliptic extended stopband LPFs exploit the mixed use of coupled-line stages and rejection stubs or even signal interference principles [1, 2]. Nevertheless, they usually require strong coupling factor coupled line sections in their circuit structures, this being a disadvantage in terms of robustness to manufacturing tolerances. Sharp rejection planar LPF with ultra wide stopband is introduced in [3]. It is based on a new class of two path bandstop transversal filtering sections (TFS) made up of a rat race directional coupler operating in transversal mode. The design exhibits a 3 dB cutoff frequency equal to 1 GHz and a 20 dB attenuated band up to 5.86 GHz. This design introduces attractive features but at the expense of increased dimensions of about (150×60) mm$^2$.

One new approach of achieving miniaturization is the use of fractal DGS structure instead of normal DGS structure. Fractal geometries have two common properties, space filling and self-similarity. Space filling property of fractal geometries can be utilized to reduce size of the filter. The increase in electrical length due to the use of the fractal curves on a fixed substrate area reduces the resonant frequency and sharpen the resonant peaks i.e. for a fixed resonant frequency the filter employing fractal DGS are smaller in size as compared to the filter employing normal DGS structure [4].

Another low pass filter design technique employing stepped-impedance hairpin resonator (SIHR) in combination with split ring resonator defected ground structure (ISRR DGS) and two elliptical DGSs is presented in [5]. This structure improves the filter characteristics such as the insertion loss, the cutoff characteristic, compact size, and ease of fabrication. But it does not reduce the filter 3dB cutoff frequency.

The LPF presented in [6] consists of double U-shaped DGS units at the ground plane and a shaped microstrip line on the top. It provides compact filter size without the need for cascading periodic DGS structures. But, it has relatively high 3dB cutoff frequency of 2.7 GHz.

In this paper, a compact microstrip low pass filter (LPF) with low 3dB cutoff frequency, ultrabroad stopband, and high stopband attenuation characteristics is introduced. A new V-shaped defected ground structure is presented. The proposed LPF design utilizes the same shaped transmission line, substrate characteristics and dimensions of the U-shaped LPF presented in [6]. But, the introduction of the V-shaped DGS allows wider stopband spectral range, sharp cutoff frequency response, and high stopband attenuation with much lower 3dB cutoff frequency. The dimensions of the V-shaped DGS controls the cutoff frequency, furthermore, it maintains the compactness of the filter size without the need for periodic DGS structures or any modifications in the transmission line shape or dimensions [7]. The proposed LPF is designed using the CST-MICROWAVE STUDIO simulator. The filter is simulated using Rogers’s RO4003 substrate of dielectric constant $\varepsilon_r=3.38$ and thickness $h=1.524$ mm.

II. PROPOSED LPF STRUCTURE

Lowering the 3dB cutoff frequency of LPFs requires larger structure size. So, a V-shaped defected ground structure is introduced. The proposed V-shaped DGS significantly reduces the LPF 3dB cutoff frequency while maintaining the same filter size. In this paper, the U-shaped LPF presented in [6] is utilized to employ the new V-shaped DGS to enhance its characteristics. The same
transmission line design, substrate characteristics and dimensions of the U-shaped LPF are used. But, the double U-shaped DGS is replaced by the proposed V-shaped DGS. Figure 1 shows the top view, shaped transmission line, of the U-shaped LPF[6]. Figure 2 shows the proposed V-shaped DGS etched in the ground plane of the filter instead of the double U-shaped DGS.

**Fig.1.** The shaped transmission line of the LPF presented in [6].

The introduction of the V-shaped DGS allows wider stopband spectral range, sharp cutoff frequency response, and high stopband attenuation with much lower 3dB cutoff frequency than the double U-shaped DGS. The dimensions of the V-shaped DGS controls the cutoff frequency, furthermore, it maintains the compactness of the filter size without the need for periodic DGS structures or any modifications in the transmission line shape or dimensions. The detailed description of the shaped transmission line dimensions as introduced in [6] is:

1. Two sections of microstrip lines of different widths ($W_2=3.53$ mm, and $W_3=1.6$ mm) and different lengths where ($T_1=19$ mm, $T_2=2.47$ mm, $T_3=11$ mm, and $T_4=3.4$ mm) as shown in Figure 1.
2. Two open circuit double stub sections of different widths ($W_3=3.53$ mm, $W_4=1.6$ mm) and different lengths ($S_1=8.235$ mm, $S_2=8.2$ mm).
3. An inset feed of width $W_{inset}=0.5$ mm and depth $L_{inset}=8.5$ mm.
In the ground plane, the V-shaped DGS is etched as shown in figure 2. The width of the V-shaped DGS arms $W_v$, the distance from the filter edge $h_v$, and the height $L_1$ control the cutoff frequency and the sharpness factor of the proposed filter. The proposed filter has been simulated using the CST-MICROWAVE STUDIO software using Rogers RO4003 substrate of dielectric constant $\varepsilon_r=3.38$ and thickness $h=1.524 \text{ mm}$ as the same as the double equilateral U-shaped DGS filter presented in [6].

### III. SIMULATION RESULTS

Generally, lowering the LPF cutoff frequency requires larger filter size. So that, the main objective of this paper is focused to reduce the 3dB cutoff frequency of a given LPF while maintaining the same filter size. For this purpose, the V-shaped DGS is introduced. In this section, several simulations for the proposed filter are performed in order to investigate the influence of V-shaped DGS cell on the filter 3dB cutoff frequency. The simulation results verified that the introduction of the V-shaped DGS cell significantly reduces the cutoff frequency of the filter. After design and optimization, the optimal dimensions of the V-shaped DGS cell that achieve 3dB cutoff frequencies ranging from 1.2 GHz to 1.688 GHz are listed in table (1). Figure 3 and figure 4 show the scattering parameters $S_{21}$ and $S_{11}$ of the proposed filter respectively compared to the corresponding parameters of the U-shaped DGS filter presented in [6].

<table>
<thead>
<tr>
<th>$w_v$ (mm)</th>
<th>$L_1$ (mm)</th>
<th>$W_v$ (mm)</th>
<th>$f_c$ (GHz)</th>
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<tr>
<td>4</td>
<td>11.826</td>
<td>1.26</td>
<td>1.688</td>
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<td></td>
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<td>0.36</td>
<td>1.2</td>
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</table>

**Table (1):** The optimal dimensions of the V-shaped DGS cell that achieve 3dB cutoff frequencies ranging from 1.2 GHz to 1.688 GHz

![Fig.3: The scattering parameters $S_{21}$ of the proposed filter compared to the corresponding parameter of the U-shaped DGS filter presented in [6].](image-url)
On the basis of these simulation results, different low pass filters having 3dB cutoff frequencies ranging from 1.2 GHz to 1.688 GHz are introduced. The simulations results indicate that the proposed filter exhibits much lower cutoff frequency than the double U-shaped filter while maintain the same compact size. It is noticed that the U-shaped DGS structure exhibits a 3dB cutoff frequency of 2.7 GHz. So, there is a reduction range in the cutoff frequency from 1.012 GHz to 1.5 GHz. But, as the reduction in the cutoff frequency increase the stopband attenuation level decrease as shown in figure 3. But, on the other hand, wide bandwidth stopband with attenuation level more than 20 dB can be obtained as in case of $W_v=1.26$ mm, and $W_v=1.08$ mm. For $W_v=1.26$ mm, a wide stopband bandwidth with attenuation level more than 20 dB from 2.22 GHz to 7.12 GHz is obtained as shown in figure 5. The proposed filter has 3dB cutoff frequency of $f_c=1.688$ GHz while the U-shaped filter has cutoff frequency of 2.7 GHz. So, there is a 1.012GHz reduction in the 3dB cutoff frequency using the same filter size (20×19) mm$^2$ reported in [6].

![Figure 4](image1.png)

**Fig.4:** The scattering parameters S11 of the proposed filter compared to the corresponding parameter of the U-shaped DGS filter presented in [6].

![Figure 5](image2.png)

**Fig.5:** The scattering parameters of the proposed V-shaped LPF compared to the scattering parameters of the U-shaped LPF presented in [6] using $W_v=1.26$ mm.
IV. MEASURED RESULTS

After design and optimization, the proposed LPF is fabricated and measured. The filter is fabricated on Rogers’s RO4003 substrate of dielectric constant $\varepsilon_r=3.38$ and thickness $h=1.524$ mm. The fabrication is done using thin film technology and photolithographic technique. The experimental measurements are done using the vector network analyzer (VNA HP8719Es). The back view and the front view photographs of the fabricated filter are shown in figure 6 (a) and (b) respectively. The measured and simulated results of the proposed filter scattering parameters are presented in figure 7, which appears a good agreement. The 3dB cutoff frequency of the fabricated filter is 1.766 GHz, that is 0.078 GHz shifted from the simulation results.

![Back view](image1.png) ![Front view](image2.png)

(a) Back view, and (b) Front view photographs of the fabricated LPF.

![Scattering parameters](chart.png)

Fig.7: The measured and simulated results of the proposed filter scattering parameters.

CONCLUSION

A class of compact microstrip low pass filter (LPF) with low 3dB cutoff frequency, ultrabroad stopband, and high stopband attenuation characteristics is proposed. It employs both shaped transmission line and a new V-shaped DGS structure techniques to achieve the aforementioned characteristics. A comparison with the low pass filter implemented using double U-shaped DGS structure having same substrate area is carried out. The simulations results indicate that the proposed filter exhibits much lower cutoff frequency than the double U-shaped filter while
maintain the same compact size. A wide stopband bandwidth with attenuation level more than 20 dB from 2.22 GHz to 7.12 GHz is obtained. Moreover, the occupied area is only (20×19) mm². The measured and simulated results of the filter scattering parameters appears a good agreement.

REFERENCES